

of the maximum and minimum for each day, and their times of occurrence, to the nearest minute; but the actual range is not given explicitly. The space allowed to the date is unnecessarily large, and it would probably be found possible to add the daily range without unduly crowding the figures. This would be a welcome addition.

An interesting feature is a list of the disturbed days, classified 1 to 4 according to the intensity. The highest figure, 4, is reserved for one or two exceptional disturbances, being applied at one or two stations only to October 30-31, 1903. Copies are also given, except in the case of Baldwin, of the curves from a considerable number of the disturbed days, the same selection being made for all the stations. This is likely to prove a valuable feature. Its value, however, is somewhat lessened by the fact that the curves are shown on a considerably reduced scale. Comparisons requiring high accuracy in the time must suffer. The fact that local time is employed is also somewhat of an obstacle to inter-comparisons. The disturbed curves are all from Eschenhagen instruments, which record all the elements on one sheet. This brings before the eye all that was happening simultaneously in the several elements. This is a distinct advantage in the study of disturbances, provided the different curves can be kept distinct. Sitka, owing to its higher latitude, is exposed to larger magnetic storms than the other stations, and the clearness of a good many of the curves reproduced suffers from crossing and confusion of the declination and horizontal force traces. October 30-31, 1903, was naturally an outstanding case of this; but on that occasion there was, besides, great loss of trace, the movements being so rapid that no clear record appeared on the photographic paper. The sensitiveness of the horizontal force instrument at Sitka was reduced towards the end of 1904 to about 1 mm.=3.7, as compared to an average of about 1 mm.=1.87 in 1902 and 1903. The sensitiveness that used to be aimed at in temperate Europe is 1 mm.=5.7, and we cannot but think that the reduction of sensitiveness in Sitka might with advantage go a good deal further than it has yet gone. Though not quite so easily effected, a reduction in the sensitiveness of the declination instrument at Sitka might also be advantageous, at least for a study of the larger features of magnetic storms. The device of two mirrors adopted in the magnetographs to avoid loss of trace is an alleviation if the movements are slow, but if, as is frequently the case, the movements are not merely large but rapid, this device may only aggravate the confusion of trace.

The volumes contain a great mass of facts, clearly printed, presented in a readily intelligible form. Having put their hand to the plough, it is to be hoped that those responsible for the work of the Coast and Geodetic Survey will not turn back until simultaneous records have been obtained for at least one sun-spot cycle at all the stations.

C. CHREE

RECENT ADVANCES IN OUR KNOWLEDGE OF SILICON AND OF ITS RELATIONS TO ORGANISED STRUCTURES.¹

NOT only is silicon widely diffused in nature in the many forms of its oxide, but it also constitutes between one-third and one-fourth of the original and non-sedimentary rocks—of which the solid crust of the earth largely consists—in these cases being chemically combined with oxygen and various metals, forming natural *silicates*. The subjoined table gives a necessarily very rough estimate of the relative proportions in which the chief constituents are present.

THE EARTH'S CRUST.

Approximate average Composition of non-sedimentary Rocks.

Oxygen ...	...	...	about 47 per cent.
Silicon ...	...	...	" 28 "
Aluminium ...	...	...	" 8 "
Iron ...	...	...	" 7 "
Calcium and magnesium ...	...	...	" 6 "
Alkali metals ...	...	...	" 4 "

¹ From a discourse delivered at the Royal Institution on Friday, May 28, by Prof. J. Emerson Reynolds, F.R.S.

The crust of the earth is, in fact, a vast assemblage of silicon compounds, and the products of their disintegration under the influence of water and other agents are the various forms of clay, sand, and chalk which constitute so large a portion of the earth's surface.

The solid crust of the earth is actually known to us for but a very few miles down—thirty at most—our deepest mines being mere scratchings on its surface; but, so far as known, practically all its constituents are fully oxidised, and this is probably true at much greater depths. During æons past oxygen has been absorbed as the earth cooled down, and the product is the crust on which we live.¹ It is probable that the proportion of oxygen diminishes away from the surface until it disappears almost wholly. What of the deeper depths? Are the comparatively light elements arranged more or less in the order of density? Are we to suppose that silicon and some carbon, aluminium, calcium, the elements chiefly comprising the crust, are those nearer the surface, and iron, copper, and the heavier metals nearer the centre?

Until recently we knew little more than that the earth is some 8000 miles in diameter, that its mean density is 5.6-5.7, and that its relatively thin outer skin, or crust, has approximately the composition already described. By a very skilful use of earthquake observations Mr. R. D. Oldham has, however, lately² given us something like a glimpse within the ball, and concludes from his observations that about five-sixths of the earth's radius includes fairly *homogeneous* material, and that the remaining sixth at the centre consists of substances of much higher density. Assuming this to be even roughly true, we conclude that silicon forms probably as great a proportion of this large mass of the earth—whether in the free state or in the forms of silicides—as it does of the crust.

Having thus magnified the office of the important element of which I wish to speak to you, I shall pass to my next point, which is how the element can be separated from quartz or other forms of the oxide, for it is never met with unless combined with oxygen in any of the rocks known to us.

I have already mentioned that quartz is a dioxide of the element—in fact it is the only known oxide—hence if we remove this oxygen we should obtain free silicon. This is not a very difficult matter, as it is only necessary to heat a mixture of finely powdered quartz with just the right proportion of metallic magnesium. The metal combines with the oxygen of the quartz, and forms therewith an oxide of magnesium, while silicon remains. If the material be heated in a glass vessel the moment of actual reduction is marked by a bright glow, which proceeds throughout the mass. When the product is thrown into diluted acid the magnesium oxide is dissolved, and nearly pure silicon is obtained as a soft, dark-brown powder, which is not soluble in the acid. This is not crystalline, but if it be heated in an electric furnace it fuses, and on cooling forms the dark crystalline substance on the table, which, as you see, resembles pretty closely the graphitic form of carbon, though its density is rather greater (2.6, graphite being 2.3).

Silicon Analogues of Carbon Compounds.

The points of physical resemblance between silicon and carbon are of small importance compared with the much deeper-rooted resemblance in chemical habits which exists between the two elements. This is expressed in the periodic table of the elements as in the following diagram:—

Na=23, Mg=24, Al=27, Si=28, P=31, S=32, Cl=35.5
Li=7, Be=9, B=11, C=12, N=14, O=16, F=19

where silicon is represented as the middle term of a period of seven elements of increasing atomic weights, just as carbon is the middle term of the previous period. The fact is, these two electro-negative or non-metallic elements play leading parts in the great drama of nature, silicon

¹ An interesting calculation has been made by Mr. Gerald Stoney, from which it appears that a stratum only 9 feet in depth of the surface of the earth contains as much oxygen as the whole of our present atmosphere. (See *Phil. Mag.*, 1800, p. 366.)

² R. D. Oldham, "Constitution of the Interior of the Earth." (Quarterly Journal of the Geological Society, vol. lxii., 1906, pp. 456-75.)

dominating that which has to do with dead matter, while carbon is the great organ-building and maintaining element of all living things. While each carries on the work to which it is best suited under existing terrestrial conditions, they both go about it in somewhat similar ways, and each one shows a tendency to overstep the border line and perform the other's part. This tendency is for various reasons much more marked in the case of carbon, but I hope to show you presently that silicon is by no means out of touch with living things, and, further, that it exhibits capacities which render it a potential element of life under other conditions of our planet, but more especially at a much higher level of temperature.

I do not propose to dwell in much detail on the remarkable parallelism of some silicon and carbon compounds, but must refer shortly to a few of them, and the oxides naturally come first.

The lecturer then described silicon oxide, chloride, bromide, chloroform, &c., with the analogous carbon compounds, and continued:—Both silicon and carbon form gaseous compounds with hydrogen of similar composition:—



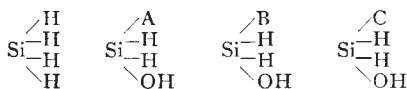
Neither of these hydrides can be obtained by direct union of the respective elements, though they are easily obtained by indirect means, with the details of which I need not trouble you. Both are colourless gases, as you see. The carbon hydride, or marsh gas, is combustible, but requires to have its temperature raised considerably before it takes fire in air, and its flame is only slightly luminous. It produces on complete oxidation water vapour and carbon dioxide gas. The analogous silicon hydride takes fire much more easily in air, and when not quite pure is even spontaneously combustible under ordinary conditions, and it burns, producing water vapour and solid silicon dioxide.

"Silico-organic Chemistry."

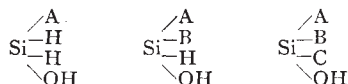
Now, just as marsh gas may be regarded as the starting point of that great branch of science which is usually spoken of as organic chemistry, so the analogous hydride of silicon is the primary compound from which many substances, which are often termed silico-organic compounds, can be derived by various means, and these were discovered in the course of the classical researches of Friedel, Crafts, Ladenburg, and others.

I wish to avoid using many chemical formulæ, which probably would convey but little meaning to some of those whom I address; it will suffice merely to indicate the lines on which investigations have proceeded in this direction.

In the older work of Friedel, Crafts, and Ladenburg, they produced complex substances by the substitution of various radicles (always carbon groups), for one atom of hydrogen in SiH_4 , and ultimately replaced another atom of hydrogen by the OH or hydroxyl group. The substances so formed were silicon alcohols, which may be represented in the following manner, A, B, and C being used to indicate the different complex replacing radicles:—



In this way silicon alcohols were built up which proved to be analogous to well-known carbon alcohols, and afforded analogous acids, &c., on oxidation. These discoveries laid the foundations of a silico-organic chemistry, and have been further extended in later years. For example, it has been found possible to pursue the analogy with known carbon compounds in the direction of replacing all the hydrogen in silicon hydride by different radicles, and these changes, which can be effected in successive stages, may be represented in harmony with those just given:—



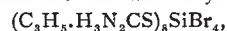
The two last of these are *asymmetric*, since all four radicles are different. Consequently, they should exist in two isomeric modifications if really analogous to known carbon compounds of the same order, and each form should be capable of acting differently on polarised light.¹ Dr. F. Stanley Kipping, who has specially investigated this kind of substitution with much success, finds that the analogy between these asymmetric silicon and carbon compounds is complete in regard to optical activity as to other general characters.

Silicon Compounds including Nitrogen.

This was all good so far as it went, but some highly important information was still wanting. As you know well, the various compounds including carbon and nitrogen play by far the most important parts in building up organised structures under the influence of vital energy, but in the silicon series we were almost wholly ignorant of the existence of such compounds until within recent years, when I undertook definitely to investigate this branch of the subject.

All that was known at the period of which I speak was that silicon forms a white nitride of uncertain composition when strongly heated in an atmosphere of nitrogen gas, and that when silicon chloride is brought in contact with ammonia and similar substances violent action occurs, but the nature of the products formed was not known owing to special practical difficulties in separating them.

The first step taken was to examine the action of silicon halides (*i.e.* chloride, bromide, &c.) on substances free from oxygen, but rich in nitrogen. The earliest of these worked with were thiocarbamides, but in all these cases the silicon halide merely united with the nitrogen compound as a whole, in some instances producing very curious substances, of which the one with allyl-thiocarbamide,



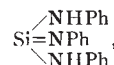
is a good example. This is a liquid which flows so slowly at ordinary temperature that it requires nearly a month in order to fall from the top of its containing tube and find its level at the bottom. Several similar substances have been obtained and examined, and their products of decomposition studied, but they do not belong to the class of which I was really in search.

It would weary you to give the details of scientific prospecting which one has to go through in order to attain definite results in a new line of work like this; suffice it to say that success attended the efforts at last, and a finely crystallised and perfectly defined compound was obtained in which silicon is wholly in direct chemical combination with nitrogen, and a specimen of that substance I now show you. Its composition is represented by the expression



where Ph stands for the phenyl group, and its name is silicophenylamide.

This substance when heated undergoes some important changes, which resemble rather closely similar changes that can be effected in analogous compounds of carbon with nitrogen. Thus it first affords a *guanidine*,



analogous to the well-known carbon guanidine, and further a di-imide, $\text{Si}(\text{NPh})_2$, which only needs the addition of a molecule of water to convert it into a silicon *urea*, $\text{SiO}(\text{NHPh})_2$. Many other substances have been produced similar to silicophenylamide, and they afford analogous products to these just mentioned; but these have been fully described elsewhere, and need not be dealt with here.

Silicon in Relation to Organised Structures.

The general results of these researches are that we now know a considerable number of silicon compounds including nitrogen, which resemble those of carbon with nitrogen, both in composition and in the general nature

¹ These changes are represented above as having been effected through the silicon alcohols in order to avoid complicating the general statement; other compounds have, in fact, been found more convenient for the purpose.

of the changes in which they can take part. Some of these carbon analogues are closely related to those which are concerned in building up organised structures of plants and animals.

All theories of life assume that its phenomena are inseparably associated with certain complex combinations of the elements carbon, nitrogen, hydrogen, and oxygen, with the occasional aid of sulphur and phosphorus. These are the elements of that protoplasm which is the physical basis of life, and by their interplay they form the unstable and complicated groupings of which that remarkable material is composed. All the phenomena we call vital are associated with the change of some protoplasm, and the oxidation of carbon and hydrogen; but it is quite open to question whether the connection of life with the elements first specified is inevitable. We can conceive the existence of similar groupings of other analogous elements forming other protoplasms capable of existing within much greater ranges of temperature than any plants or animals now known to us have to withstand. For example, we can imagine a high-temperature protoplasm in which silicon takes the place of carbon, sulphur of oxygen, and phosphorus of nitrogen, either wholly or in part. In fact, protoplasm, so far as we know it in purest form,

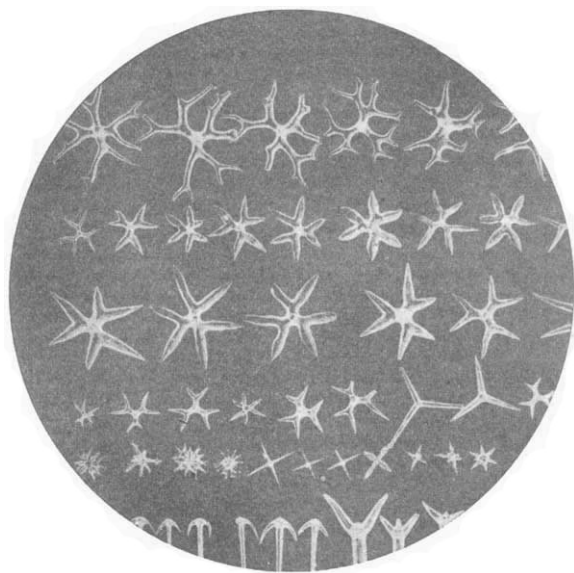


FIG. 1.

always contains some sulphur, and often a little phosphorus, representing a very partial substitution of the kind in question.

In view of our newer knowledge there is, therefore, nothing very far-fetched in supposing that under suitable conditions a plant or an animal organism may be able to construct from silicon compounds, ultimately derived from the soil, something akin to silicon protoplasm for use in its structures.

You will now ask me whether there is any evidence that anything of this kind actually occurs in nature. I think there is, although I admit that the evidence is not very varied so far as we yet know.

First, as to the *vegetable* kingdom. It is well known that many plants take up silicon in some form from the soil, and use it in ways which my botanical friends tell me they do not at present understand. Silicon is present in the straw of cereals, such as wheat, oats, &c., and in most of the Gramineæ. It was supposed that the stiffness of the straw was secured by a siliceous varnish, but this view is not now in favour, as it has been found possible to remove silica from the straw by careful treatment without diminishing its rigidity. It is also present in the

leaves of some palms, for my friend, Dr. Hugo Müller, in the course of his extensive researches on the sugars present in certain palm leaves, has been much troubled by the presence in the extract from the leaves of siliceous compounds of unknown nature. Again, a well-known substance called "tabasheer," consisting largely of hydrated silica, including some organic matter, is obtained at the nodes of some bamboos. What purpose silicon serves in these plants, which seem to have special need for it, we do not know, but the subject appears to be well worth closer examination than it has yet received at the hands of plant physiologists.

I have on the table some good specimens of tabasheer, and can show some portions on the screen which have been rendered nearly transparent by soaking in benzene, and under these conditions exhibit traces of structure.

Next, as to the *animal* kingdom. The most satisfactory evidence that we can at present offer as to the organ-building capacity of silicon comes, curiously enough, from some of the simpler organisms of the animal kingdom, but the only group the short remaining time at my disposal permits me to notice is that of the *sponges*.

You know that these curious forms of undoubted animal life live in sea-water, and are usually anchored to rocks. The sea contains a very minute proportion of silica in solution, and the sponge has the power of appropriating very considerable quantities in the course of its life and as a part of its normal food supply. What does it do with this silica? It appears to use it in cell production, and from the cell evolves the beautiful and minute siliceous spicules which are so abundant throughout the structure of many of the sponges.

I have here some photographs of these spicules which I have had taken, and shall throw them on the screen. Two of the best of them have been made from microscopic specimens kindly lent to me by Prof. Dendy, who has made a special study of these spicules and of their modes of growth. One of these slides is reproduced in the engraving (Fig. 1).

These structures do not represent mere incrustations, but rather definite growths from the cell protoplasm, and are themselves in the nature of cells of characteristic forms. Prof. Dendy informs me that these spicules in certain cases become surrounded by a horny substance and seem to die, as if by cutting off the supply of energy as well as growing material.

In some of the larger sponges, as in the beautiful *Euplectella aspergillum*, or "Venus' flower basket," represented in Fig. 2, the siliceous material constitutes the greater part of the sponge, as the soft portion resembles a somewhat gelatinous coating from which the exquisite siliceous structure is developed.

To sum up, then, I have shown that silicon can easily take the place of carbon in many nitrogen compounds, as well as in others not including nitrogen. It therefore seems to me that we hazard no very violent hypothesis in supposing that the silicon which enters the sponge in its food, probably as an alkaline silicate, is in the marvellous animal laboratory made to take the place of a portion of the carbon of the protoplasm from which the spicules are ultimately developed.

The hypothesis is at any rate suggestive, and I hope enough has been said to commend it to your consideration, for there seems to be no doubt that silicon is capable of playing a larger part as an "organic element" than we hitherto had reason to suppose.

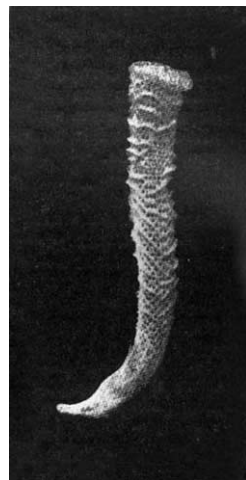


FIG. 2.